Department of Agriculture and Fisheries for Scotland in Association with the Atlantic Salmon Trust

The Movements of Adult Atlantic Salmon in the River Tay

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John Webb

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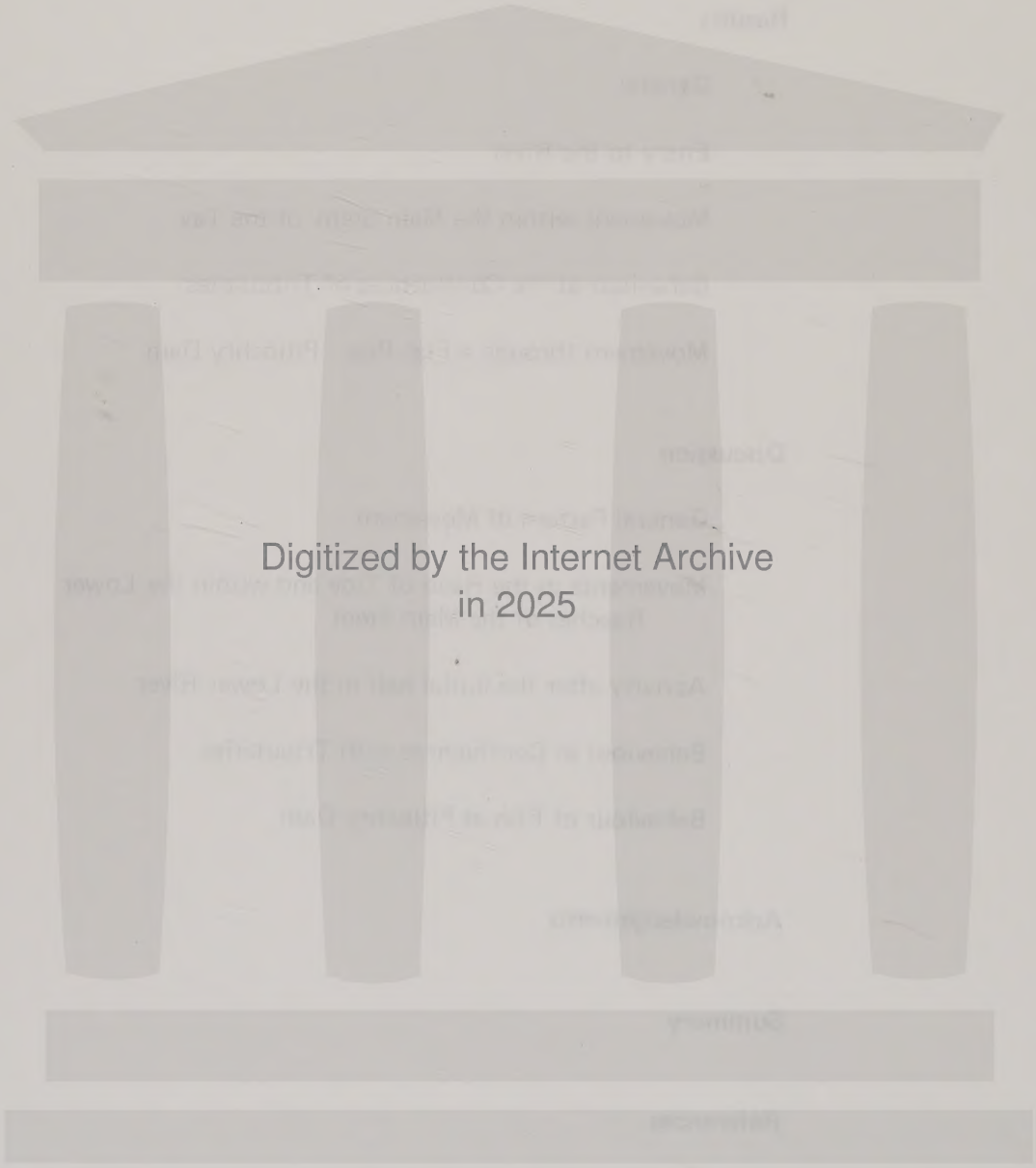

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The Movements of Adult Atlantic Salmon in the River Tay

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Introduction

In 1987, the Department of Agriculture and Fisheries for Scotland and the Atlantic Salmon Trust began a study of the movements of salmon entering and ascending the River Tay in eastern Scotland. Fish caught in the upper Tay estuary during June and July were tagged with radio transmitters, released, and their subsequent movements examined. The study was aimed at determining those factors controlling the movements of fish within the estuary, in the lower reaches of the river and into the major tributaries of the Tay. Particular attention was paid to the role of water flow in regulating entry to the river, controlling movements within the main stem and subsequently influencing the timing of entry into the tributaries.

Radio telemetry is becoming increasingly popular as a technique for recording the movements of individual adult salmon. A range of studies has been carried out using both this technique and the parallel technique of acoustic tagging, to establish a more detailed picture of the patterns of movement of Atlantic salmon *Salmo salar* L. in coastal waters (Hawkins, Urquhart and Shearer, 1979; Smith, Hawkins and Shearer, 1981) within estuaries (Stasko, 1975; Brawn, 1982; Potter, 1988; Priede, Solbe, Nott. Grady and Cragg-Hine, 1988; Solomon and Potter, 1988), within selected river catchments (Hawkins and Smith, 1986) and as they enter tributaries for spawning (Webb and Hawkins, 1989).

This report presents the results of studies carried out on the Tay in 1987, when 44 salmon were tagged and followed.

The Tay System

The river Tay has been described as the greatest salmon river in Scotland. It has the seventh largest drainage basin in Britain with a combined drainage area of approximately 6,000 km^2 (2,300 square miles) of central Scotland, containing seventy fresh-water lochs. The average annual rainfall varies from 3200 to 760 mm (125 to 30in) depending on the area. Carrying more water than the rivers Thames and Severn combined, the Tay system has 11 main tributaries, including the rivers Garry, Tilt, Tummel, Isla, Almond, Lyon and Earn.

The furthest western source of the Tay rises from the slopes of Ben Lui (1,128 m) on the eastern slopes of Argyll and emerges from Loch Dochart and Loch Dubhair as the principal tributary of the system, the Dochart entering Loch Tay at Killin. The Tay proper emerges from the eastern end of the loch at Kenmore. The biggest tributary is the river Tummel, flowing to its junction with the Tay at Ballinluig. Passing Dunkeld, the main river enters the wide valley of Strathmore, where at Kinclaven it is joined by its second largest tributary, the Isla, flowing from both the Isla and Ericht catchments covering the southern slopes of the Grampians and the plains of Strathisla. From Isla Mouth the river turns south to Perth, 24 km (15 miles) down stream, being joined by the river Almond on the outskirts of the town at Scone. It is below Perth that the river enters the main part of the upper estuary, turning east and then north-east to enter the North Sea to the east of the city of Dundee. The upper limit of the tide is some 3 km above the city of Perth in the area of the Woody Islands below the junction with the river Almond at Scone. The exclusively tidal fresh-water reaches of the estuary extend from the upper limit of the saline intrusion at Newburgh to Scone (see Figs 1 and 2).

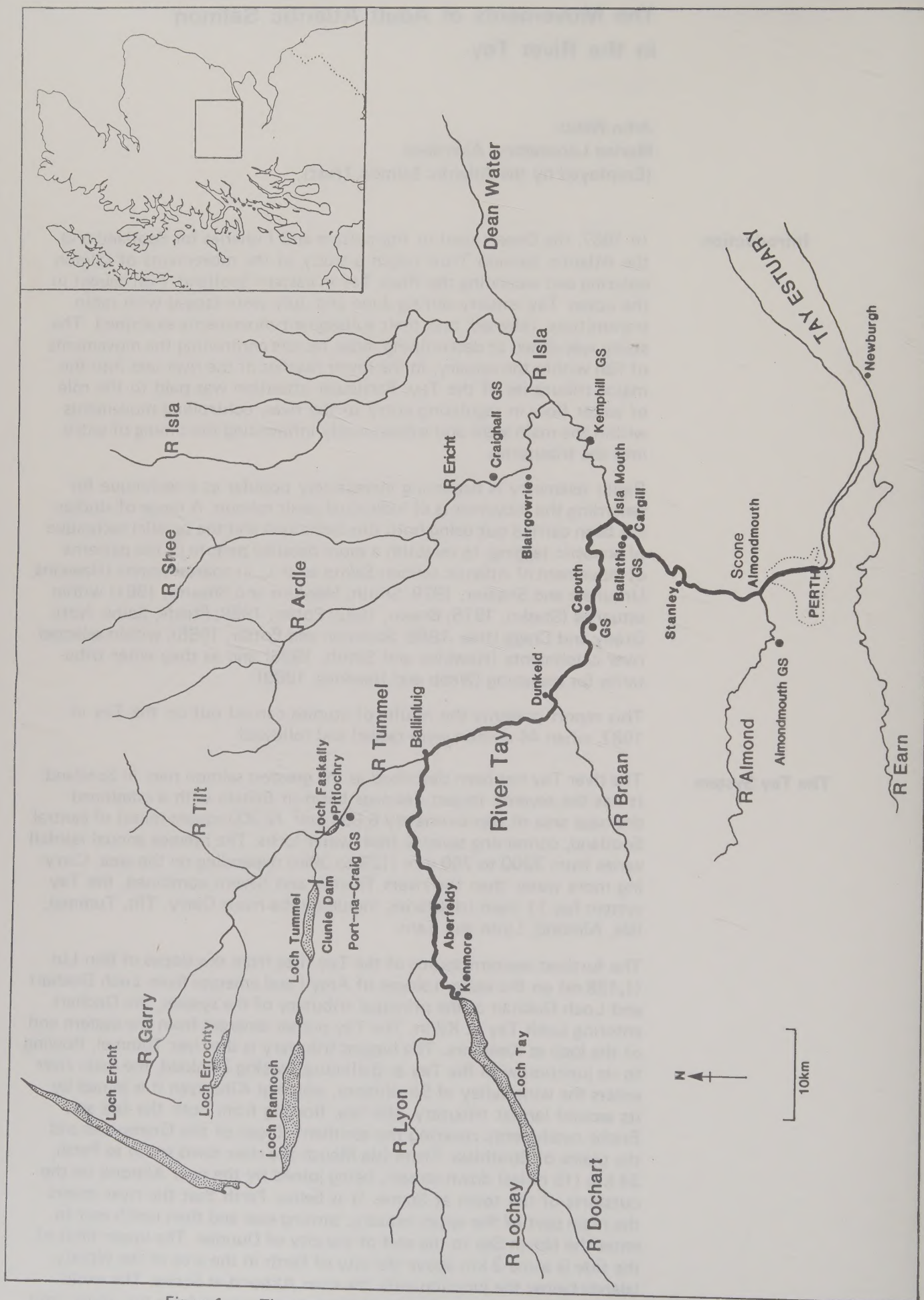


Figure 1. The river Tay catchment, showing the main tributaries and lochs. The positions of the flow gauging stations (GS) are also shown.

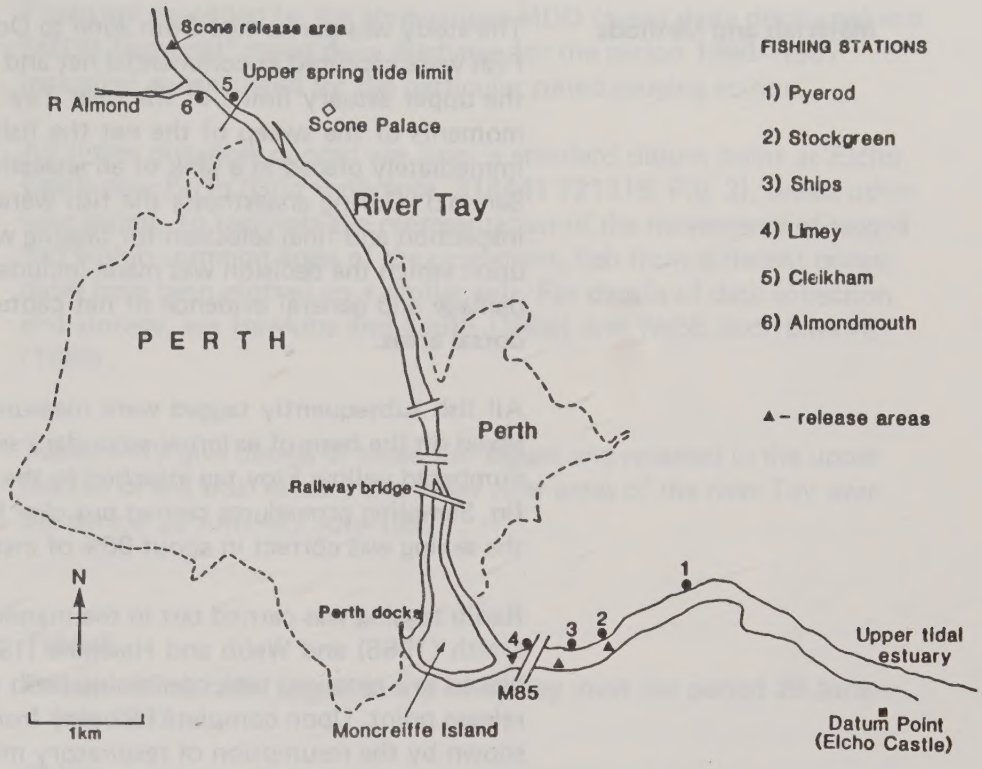


Figure 2. **The upper Tay estuary and lower river Tay at Perth, showing the location of the netting stations where fish were captured and tagged, and subsequent release areas. Other key features labelled include the Perth city bridges and the upper limit of tidal influence, at Scone.**

From the eastern end of Loch Tay the river descends 106 m in the remaining 188 km before entering the sea. Despite the absence of falls and rapids and the generally low gradient, the Tay is the fastest flowing major river after the Spey. Under high discharge conditions mid-stream water velocities at Ballathie of 3.3 m s^{-1} are not uncommon.

Detailed descriptions of the Tay as a salmon river have been provided by Calderwood (1907), Mills and Graesser (1981), Ashley-Cooper (1987), and Campbell (1987). In keeping with its size, the river has traditionally yielded large numbers of salmon to both the commercial and recreational fisheries, with a total catch of about 50,000 salmon and grilse per year.

Despite having the greatest range of seasonal 'runs' of fish of any river in Scotland, the river has historically been considered to be primarily a spring and autumn system. Like many of the larger salmon rivers on the east coast of Scotland, the numbers of spring fish returning to the river (those fish caught from January until the end of April) have declined since the 1950s.

Since the 1930s, a significant part of the Tay catchment has been subject to extensive development for hydro-electric power generation. The overall effect on the stocks of salmonid fish within the catchment has yet to be assessed. Prior to the completion of the schemes, the combined flow of the Tay and the Earn reached a nadir of 270 million gallons per day during the drought of 1955. The minimum average daily flow from the system (including the river Earn), measured from completion of the hydro-electric developments to 1974, was 740 million gallons per day, as a consequence of the regulation of flow by various hydro-electric schemes. The increase was a consequence of the delayed release of stored winter discharges (Pontin and Reid, 1974/75).

Materials and Methods

The study was performed from June to October 1987.
Fish were captured at commercial net and coble fishery stations within the upper estuary limits of the river Tay (Figs 1 and 2). In the final moments of the sweep of the net the fish were quickly removed and immediately placed in a tank of an anaesthetic solution (1:10,000 MS222, Sandoz). During anaesthesia the fish were subject to a thorough visual inspection and final selection for tagging was performed. Objective criteria upon which the decision was made included the degree of scale loss, fin damage and general evidence of net capture damage on the snout and dorsal areas.

All fish subsequently tagged were measured from snout to fork and sexed on the basis of external secondary sexual characteristics, and had a numbered yellow Floy tag attached to the rear basal area of the dorsal fin. Sampling procedures carried out over the same period suggested that the sexing was correct in about 90% of instances.

Radio tagging was carried out in the manner described by Hawkins and Smith (1986) and Webb and Hawkins (1989). After tagging, fish were placed in a recovery tank containing fresh water and transported to the release point. Upon complete recovery from the effects of the anaesthetic, shown by the resumption of respiratory movements and active swimming, all tagged fish were released within 5–8 minutes of their initial capture. Those fish which failed to recover in a satisfactory manner within a few minutes of tagging were rejected and the tag was removed. Fish taken from the Stock Green (Tay Salmon Fishing Company Ltd) and Ships (Inch Fishing Company Ltd), fishing stations were released either opposite their respective capture stations or in the vicinity of the shot head (the upper operational limit) of the Limey fishing station (Tay Salmon Fishing Company Ltd). Those fish taken from the Cleikham station Scone Palace Estate) were released in the first pool above the Almondmouth fishing station (Fig. 2). Tracking was begun at the cessation of the particular tagging shift period. The positions of the net and coble fishing stations and release areas are shown in Figures 1 and 2.

Details of the tags, the operation and deployment of automatic listening stations (or ALSTNs), the active tracking techniques and methods of data collection are given by Hawkins and Smith (1986) and Webb and Hawkins (1989). Daily tracking was carried out from the bank from the date of release of the first fish on 29 June until 3 August. Periodic bank and aerial tracking then took place up until 24 September. Passive monitoring by the ALSTNs continued in the area of the Isla/Tay confluence until mid-October, whereupon all the tracking ceased. Consequently, the spawning sites of the tagged fish were not determined. Rates of progression are based on calculations made on data derived from ALSTNs only, thereby providing the most accurate indication of progression in either direction. Radio-tagged fish were subsequently identified by their characteristic frequencies and pulse rates. Individual fish were assigned code numbers ie, F1, F2, etc.

Discharge and water level data from the Ballathie (Tay), Caputh (Tay), Craighall (Ericht), Kemphill (Isla), Port-na-Craig (Tummel) and Almondbank (Almond) metering stations were provided by the Tay River Purification Board, Perth. Owing to the unavailability of detailed discharge data from the Kemphill station (lower Isla), data from the Craighall station were taken as representative of flows within the Isla catchment. The positions of these flow monitoring stations are shown in Figure 2.

Flows are described by the abreviations MDD (mean daily discharge) and SMDD (seasonal* mean daily discharge for the period 1986–1987 inclusive) as calculated for the particular stated gauging station.

All linear distances quoted are from a standard datum point at Elcho Castle near Perth (Grid Reference, 316441 721316, Fig. 2), unless otherwise stated. To facilitate the representation of the movements of tagged fish within common areas of the catchment, fish from different release dates have been plotted on a similar axis. For details of data collection and storage, see Hawkins and Smith (1986) and Webb and Hawkins (1989).

Results

General

Tables I–IV give details of those fish tagged and released in the upper reaches of the tidal estuary and lower river areas of the river Tay over the period 29 June–27 July 1987.

Table I

Details of fish radio tagged in the River Tay over the period 29 June–4 July 1987

Fish No.	Capture site	Release site	Sex	Length (cm)	Release time	Notes
29 June. High tide: 17.49 Height : 4.7 m						
F1	Stockgreen	Opposite capture station	M	58	17.10	Tracked to Isla
F2			M	54	17.45	Entered river to Stanley, recaptured at Ships 19.45, 30.6.87
F3			M	63	18.00	Recaptured at Cleikham 01.30, 30.6.87
F4			M	68	18.35	Tracked to Loch Faskally
F5			F	53	18.50	Tracked to Isla
F6			M	69	18.55	Recaptured at Ships
F7			M	67	19.20	Recaptured at Stockgreen
30 June. High Tide: 18.27 Height : 4.6 m						
F8	Stockgreen	Opposite capture station	M	61.5	17.20	Recaptured at Stockgreen
F9			M	67.5	18.25	Recaptured at Ships
F10			M	66	19.20	Recaptured at Ships
F11			M	66	19.45	Recaptured at Cleikham
4 July. High Tide: 08.32 Height : 4.5 m						
F12	Ships	Opposite capture station	M	67.5	08.40	Tracked to Isla Mouth
F13			M	67.5	09.20	Tracked to Isla

* Denotes monthly mean daily discharge.

Table II
Details of fish radio tagged in the River Tay over the period 8–16 July 1987

Fish No.	Capture site	Release site	Sex	Length (cm)	Release time	Notes
8 July High Tide : 12.49 Height : 4.6 m						
F14	Ships	Opposite capture station	M	62	12.15	Not located
F15			M	58	12.30	Recaptured by Pyerod
F16			M	62	13.05	Tracked to Isla/Ericht until captured by an angler
F17			M	58	13.40	Recaptured by Ships
F18			M	59	13.45	Tracked to Isla Mouth
F19			M	64	13.51	Recaptured by Pyerod
10 July. High Tide: 14.50 Height : 5 m						
F20	Ships	Limey Shot Head	F	57	14.44	Recaptured at Limey
F21			M	62	14.25	Recaptured at Ships
F22			M	63	14.03	Recaptured at Ships
16 July. High tide: 07.07 Height : 5.2 m						
F23	Ships	Limey Shot Head	M	63	10.35	Tracked to Stanley
F24			M	57	11.05	Tracked to Stenton
F25			M	62	11.45	Tracked to Taymount

Table III
Details of those fish radio tagged in the River Tay over the period 17–21 July 1987

Fish No.	Capture site	Release site	Sex	Length (cm)	Release time	Notes
17 July. High Tide: 08.00 Height : 5 m High Tide: 20.51 Height : 4.5 m						
F26	Stockgreen	Limey Shot Head	M	61	08.41	Tracked to Taymount
F27			M	59	10.44	Tracked to Isla
F28		(Salmon)	M	91	19.25	Tracked to Almond Mouth
18 July. High Tide: 08.56 Height : 4.8 m						
F29	Stockgreen	Limey Shot Head	M	61	08.05	Tracked to Aberfeldy
F30			M	62	08.30	Recaptured at Ships, 09.30
F31			M	68	09.20	Tracked to Isla Mouth
F32			F	67	10.40	Tracked to Isla
21 July High Tide: 12.24 Height : 4.2 m						
F33	Ships	Lime Shot Head	M	57	10.44	Recaptured at Limey 13.30
F34			M	58	12.30	Recaptured at Ships
F35			M	59	13.03	No Data
F36			M	64	13.03	Recaptured at Ships
F37			M	58.5	13.25	Recaptured at Ships

Table IV

Details of those fish radio tagged in the River Tay over the period 22–27 July 1987

22 July. High Tide: 13.29 Height : 4.3 m						
F38	Ships	Limey Shot Head	M	57	13.50	Tracked to Campsie Linn
F39			F	61	14.30	Recaptured at Ships 23.30, 22.07.87
F40			M	64	14.45	Recaptured at Cleikham 22.07.87
F41			M	57	15.45	No Data
27 July. High Tide: 04.16 Height : 5.0 m						
F42	Cleikham (Scone)	Almond Mouth	M	62	08.21	Tracked to Cargill
F43			M	67	08.21	Tracked to Stanley
F44			M	66.5	08.45	Tracked to Lower Redgorten

In total, 43 grilse (one sea-winter fish) and one salmon (multi sea-winter fish) were tagged. Twenty-one of the fish released within the upper tidal reaches of the estuary were subsequently recaptured by the sweep-netting fishery, and twenty of these were not observed moving above Almondmouth. All reported recaptures were either from netting stations within the upper estuary (Pyerod, Stock Green, Ships and Limey) or stations operating above the tidal limit at Scone (Cleikham and Almondmouth). The positions of the fishing stations and release points within the catchment are shown in Figure 2.

Five fish were subsequently recaptured at the netting station from which they were released (F7, F8, F17, F20, F33). Seven fish were recaptured at fishing stations up stream from the release point, (F2, F3, F6, F9, F10, F11 and F40) including three taken at the Cleikham and Almondmouth stations (F3, F10 and F40). Eight fish were recaptured by fishing stations down stream of the release site (F15, F19, F21, F22, F29, F34, F36, F37, and F39). The lowest recaptures within the estuary (F15, F19) were at the Pyerod fishing station (Fig. 2). One fish (F2) was recaptured after ascending past the upper tidal limit to Stanley (19 km), and then proceeding back down stream. A thorough inspection of the fish on the bank after recapture at the Pyerod fishing station did not reveal any physical damage which might have led to the behaviour recorded. Three fish (F14, F35 and F41) were neither reported as being recaptured nor located within the main river despite extensive aerial searching. Thus, of the 44 fishes tagged, 23 ascended the river above the Almondmouth/ Cleikham area of which 22 were subsequently followed further up stream.

Entry to the River

Some fish were located several times in the upper estuary before either being recaptured or moving above the tidal limit. The majority of these observations were made in the area of the seaward end of Moncrieffe Island, Perth docks and the pools in the area of the Perth bridges.

Tagged fish entered the river above the point of highest tidal influence over the period 29 June to 23 July. Entry took place over a range of discharges recorded at Ballathie : the lowest mean daily flow (46.88 m^3 s^{-1} ; 70.8% SMDD) was recorded on 10 July, as was the lowest discharge (46.53 m^3 m^{-1}). The highest mean daily flow was on the 18th July (175.8 m^3 s^{-1} ; 265% SMDD) as was the highest recorded discharge

over the entry period (198.2 m^3 s^{-1}; 299% SMDD). Further details of prevailing main-stem flows (exclusive of the river Almond) over the period when tagged fish entered the river are shown in Table V.

Of the 22 fish that entered the main Tay, 18 moved up stream without significant delay except in the area of the Perth bridges, where delays of *ca* 3–25 minutes were observed. Most fish passed the Almondmouth area within 8 hours of release.

Table V shows the range of rates of progression up stream from the release areas for those fish showing continuous movement up stream (based on the timing of first reception at the ALSTN positioned in the area of Almondmouth, Fig. 2). Details of mean daily discharge over this period, recorded at Ballathie, are also shown.

Table V

Summary of the calculated rates of progression of radio tagged salmon during initial river entry* and ascent period from their respective release areas in the upper Tay estuary to the area of the Tay/Almond confluence; 29 June–18 July 1987

Fish No.	Date	Release Time	Almondmouth (GMT)	Rate of progression km d^{-1}	Mean daily discharge (m^3 s^{-1})†
F1	29.6	17.10	00.10 (30,6)	25.9	69.5
F2	29.6	17.45	23.05	25.3	69.5
F4	29.6	18.35	00.20 (30,6)	33.9	69.5
F5	29.6	18.50	22.50	45.3	69.5
F12	04.7	08.40	12.16	(a) 44.7	53.7
				(b) 172	53.7
F13	04.7	09.20	12.40	(a) 56.5	53.7
				(b) 152	53.7
F16	08.7	13.05	16.15	56.0	48.3
F23	16.7	10.35	15.50	(a) 31.8	134.8
				(b) 32.5	134.8
F24	16.7	11.05	17.45	(a) 25.0	134.8
				(b) 28.9	134.8
F25	16.7	11.45	17.25	31.5	134.8
F27	17.7	10.44	16.35	(a) 28.5	137.5
				(b) 36.4	137.5
F31	18.7	09.20	12.55	46.4	52.3

* Calculated only for those fish considered to move continuously in their initial phase of migration through and above the upper tidal limit.
Note: All rates of progression were calculated over the distance from the respective release points to the Almondmouth automatic listening station (ALSTN).

† Mean daily discharge recorded at Ballathie flow gauging station.

The mean rate of progression (or net ground speed) of fish from their respective release areas to the confluence of the Tay and Almond was 37.5 km d^{-1}, with the highest rates of movement being observed within a 4.31 km length of the river by F12, moving at an equivalent ground speed of 7.1 km h^{-1} (170 km d^{-1}), and within a 2.54 km length of river above the highest Perth road bridge (Fig. 2) by F13 at 6.35 km h^{-1} (152.4 km d^{-1}). Movements to the Almond/Tay confluence at Scone were compared with the prevailing flows but no clear relationships could be discerned. The movements of four fish (F18, F26, F28, F29) within

the same area of the upper estuary were examined over a longer time period. Details of the movements of these fish and the range of mean daily discharges over the relevant periods are shown in Table VI. Delay in the ascent from the release point to the area of the confluence of the Tay with the Almond was observed over a range of maximum and minimum daily flows (measured at Ballathie) of 47–198 m^3 s^{-1} (72.5–299% SMDD; July).

Table VI

The timing* of release and subsequent arrival at the area of the Tay/Almond confluence of those radio-tagged salmon passing the confluence area in a period of greater than eight hours after their respective release times; 29 June–27 July 1987

Fish No.	Date of release date/time*	Almondmouth date/time*	Discharge range m^3 s^{-1}†	% Range of seasonal mean daily discharge**
F18	08.07 (14.40)	11.07 (22.25)	48 (47–48) – 63 (49–74)	72.5 – 95
F26	17.07 (08.40)	24.07 (00.15)	59 (55–62) – 137 (100–173)	89 – 206
F28	17.07 (19.25)	18.07 (07.40)	137 (100–173) – 175 (145–198)	206 – 264
F29	18.07 (08.05)	19.07 (12.20)	167 (138–191) – 175 (198–145)	252 – 264

* All times are GMT

† Discharges recorded at Ballathie station. Figures outwith brackets: Mean daily flows

** Calculated for the period 1976–1987 inclusive

Fish 18 remained in the area of Perth docks for *ca* 3 days over a range of MDD corresponding to 70.8–73.7% SMDD (July). Movement through the head of tide and past Almondmouth on 11 July (Table VI) was associated with an increase in main-stem flow to *ca* 59 m^3 s^{-1} (89% SMDD; July). Similarly, despite concurrent MDD discharges greatly in excess of the seasonal norm (Table VI), both F28 and F29 resumed ascent through the head of tide at instantaneous flows greater than associated with both their release and subsequent delay (179 and 199% SMDD, respectively). The maximum delay was shown by F26, passing Almondmouth approximately 6 days and 14.5 h after release (Tables III and VI). The delay coincided with a general decline in main-stem discharges from significantly elevated levels (*ca* 37% of maximum pertaining flows recorded over the duration of the residence period) recorded over the previous eight days. Subsequent movement through the Tay/Almond confluence coincided with instantaneous flows of *ca* 50m^3 s^{-1}, corresponding to *ca* 76% of the SMDD (July).

Table VII shows the period in which tagged fish were within the reception range of the ALSTN at Almondmouth. Discharge of the main-stem Tay and river Almond is shown for comparison. The duration of reception was correlated with main-stem flow ($P<0.05$), the longest period of continuous radio reception within this area coinciding with some of the highest main-stem Tay and river Almond flows recorded over the tagging period.

Figure 3 illustrates the movements in the lower reaches of the main stem Tay of all radio-tagged fish that ascended above the area of the Tay/Almond confluence. The subsequent down-stream movements of F2 have been ommitted for clarity. The range of daily discharge levels measured at Ballathie over this period are also shown. With the exception of F42, F43 and F44 (captured and subsequently released above the upper tidal limits; Table IV), there is a marked similarity in the rate of ascent (as indicated by the slope of the plotted tracks) through this area of the upper estuary and lower river. Those fish ascending this part of the river in the latter half of the tagging/release period, from mid-July (Tables III and IV), appeared to stop at lower levels within the river than those released earlier.

Table VII

Reception period of salmon passing Tay/Almond confluence ALSTN during initial ascent period; 26 June–24 July 1987

Date	Fish No.	Reception period (h. min)	Mean daily flow Ballathie (m^3 s^{-1})	Mean daily flow Almondbank (m^3 s^{-1})
29.6.87	F5	0.40	69.5	1.94
	F2	<0.05	69.5	1.94
	F4	1.20	69.5	1.94
	F1	0.45	69.5	1.94
04.7.87	F12	<0.05	48.3	1.34
	F13	0.04	48.3	1.35
08.7.87	F16	<0.05	48.3	1.07
10.7.87	F18	0.16	46.8	1.11
16.7.87	F23	0.10	134.0	4.40
	F25	<0.05	134.0	4.40
	F24	0.16	134.0	4.40
17.7.87	F27	0.20	137.0	4.10
18.7.87	F31	0.15	175.0	6.37
	F28	6.20	175.0	6.37
	F32	3.40	175.0	6.37
19.7.87	F29	0.35	167.0	5.75
23.7.87	F38	0.10	63.0	2.14
24.7.87	F26	0.20	59.4	1.85

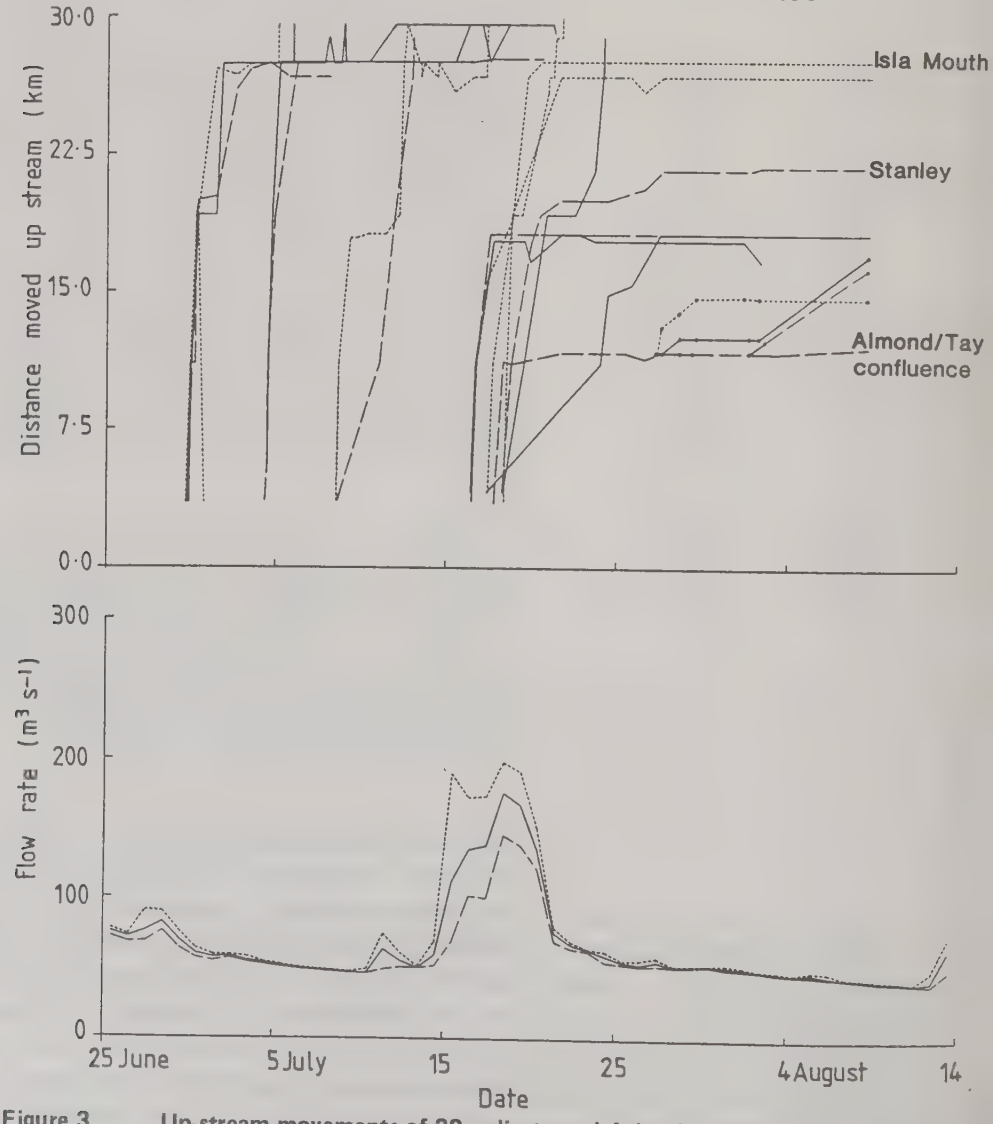


Figure 3. **Up-stream movements of 22 radio tagged Atlantic salmon in the river Tay, from their respective release areas, up to the area of the Tay/Isla confluence. Mean, maximum and minimum daily flows (m^3 s^{-1}) measured at Ballathie are also shown.**

Of the different groups of fish tagged (Tables I–IV), those released on 29 June (F1, F2, F4 and F5) showed the most consistent behaviour, both within the very highest reaches of the estuary (as illustrated by their respective arrival times at the Tay/Almond confluence, Table V), and within the lower river to Stanley, 8.12 km further up stream. The arrival of F5, F4 and F2 at Stanley Mill (19 km) was monitored by an ALSTN on the morning of 30 July, the three fish entering its reception area within a period of less than ten minutes (06.25–06.30, GMT), with F1 following at 08.50. With the exception of F2, all these fish continued on to Isla Mouth within 8 hours of passing the ALSTN at Stanley. Similarly, F12 and F13, released on 4 July (Table I), were later located below the railway bridge in Perth at 11.55 and 11.40 respectively, passing the Almondmouth area at 12.16 and 12.40 and reaching Stanley later that day at 21.40 and 17.21.

The timing of movement of many fish through ALSTNs positioned on the lower beats of the river was determined by the timing of ascent through the area of the head of tide at Scone, fish continuing in a more or less continuous manner to their first stopping position.

The calculated equivalent net rates of progression (ground speed) of these fish, from the area of the Almondmouth to Stanley, are shown in Table VIII. With the exception of F13, the rates of progression recorded from the different fish are very similar.

Table VIII

Calculated rates of progression by radio tagged grilse associated with the continuous initial river penetration period from Almondmouth to Stanley

Date	Fish No.	Length (cm)	Almondmouth (time)	Stanley (time)	Rate of progression (km d^{-1})
29/30 June	F5	53	22.50	06.30	25.4
	F2	54	23.05	06.25	26.6
	F4	68	23.20	06.25	27.5
	F1	58	23.50	08.50	24.3
04 July	F12	67.5	12.16	21.40	20.7
	F13	67.5	12.40	17.21	41.2

Fish F2, released on 29 June, ascended to the area of the weir above Stanley (Fig. 1) within minutes of the similar ascent by F1, F4 and F5, released on the same tagging shift (Table I). Despite the similarity in the rate of progression (Tables V and VIII), F2 was subsequently detected again by the ALSTN at Stanley (at 09.25–09.30) as it moved back down stream towards the tidal part of the river the following day. It was subsequently recaptured by a netting station within the upper tidal reaches below Perth on the evening tide of 30 June (Table I).

Movement Within the Main Stem of the Tay

With the exception of those fish tagged and released from areas above the highest tidal influence at Scone (F42, F43, and F44), the behaviour of

tagged fish entering the lower reaches of the river from below the tidal limits, can be divided into two main phases:

i. An initial period of river entry. The fish progressed up stream through the upper estuary and subsequently moved continuously up stream within the lower reaches of the river throughout a range of flow conditions and times of day. This activity occurred over a period of up to 24–30 h.

ii. A later period in which movement up stream became discontinuous or ceased for varying periods of time.

Figures 4–13 show the general movements of those tagged fish monitored above the Tay/Almond confluence over the study period. Those movements observed by daily tracking are illustrated (joined points) together with single isolated observations in the later stages of the study period (single points).

Of the twenty-one fish subsequently tracked higher than Almondmouth, five were observed to enter the middle reaches of the Tay above the area of the Isla/Tay confluence.

The highest penetration observed (in terms of linear distance from the release area) was by grilse F29 (Fig. 4). Released on 18 July (Table II) it proceeded through the lower beats to Isla Mouth by 24 July, continuing through the middle reaches of the Tay to the area above the Bran confluence at Dunkeld (46.9 km) on 31 July. It passed through the Kinnaird beats and the Tay/Tummel confluence at Ballinluig (53 km) in the first two days of August. It was subsequently located on 27 September approximately 4.3 km down stream of the Tay/Lyon confluence near Aberfeldy, where it remained until the last observation on 2 October. An ALSTN placed on the Tay above the Tay/Lyon confluence (80.8 km) showed no evidence of a received signal by the end of October, suggesting that the fish might have entered the Lyon over this period.

One fish entered the river Tummel (F4: Table I), ascending the fishladder and remaining in Loch Faskally until the last observation on the 27 September. Its movements over the study period are described in detail later.

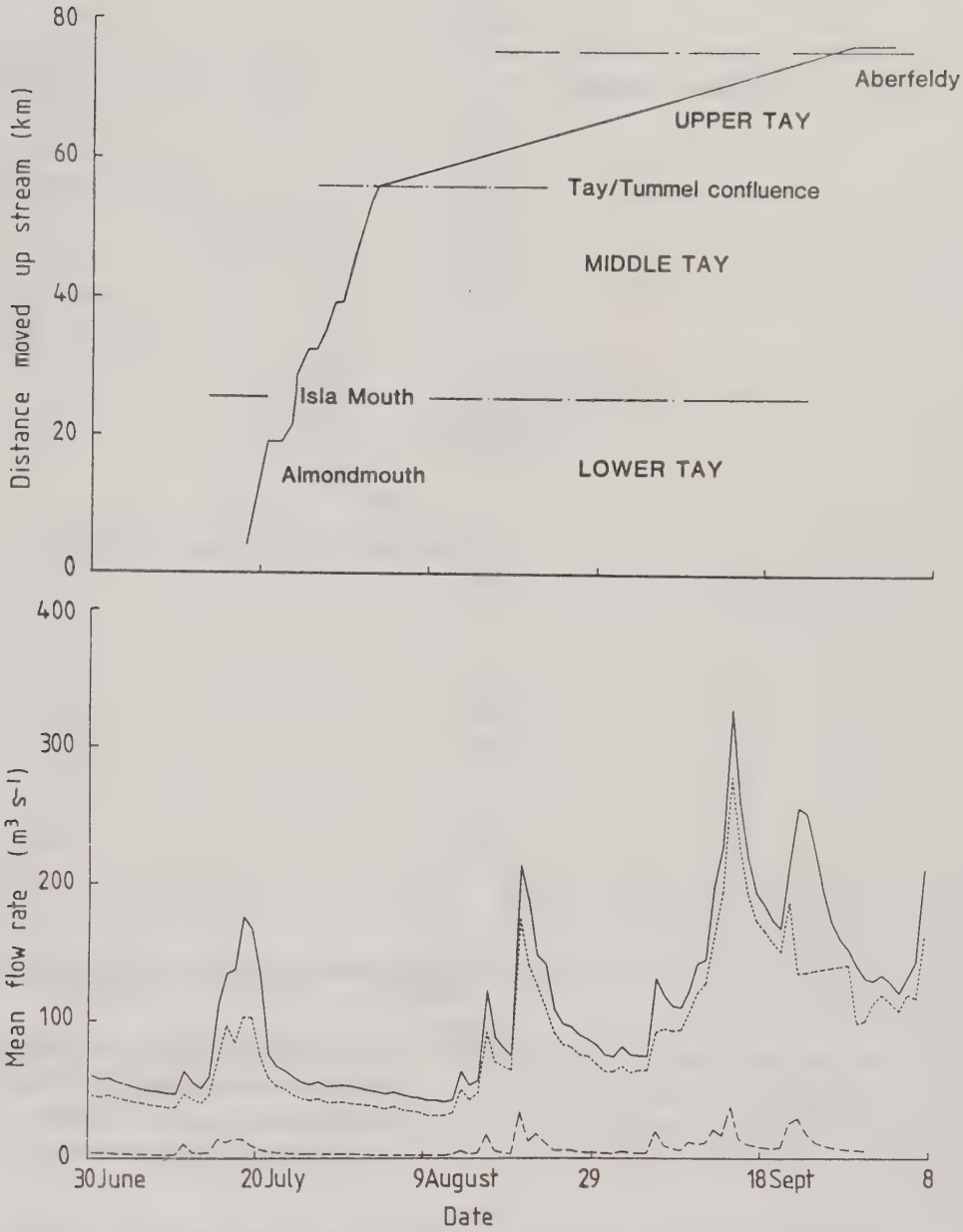


Figure 4. **The movements of F29 within the main stem Tay. Mean daily flows recorded at Ballathie _____ Caputh ..... and Craighall - - - - - - - - - - - - - - - are also shown.**

The movements of those fish captured and subsequently released above the tidal limits at Scone (F42, F43, F44: Table IV) together with fishes F27, F28, F32 and F38 are shown in Figure 5. After release, sustained movement like that shown by fish tagged within the estuary was not observed. Migratory activity was sporadic with all three fish remaining below the Tay/Isla confluence by the end of the observation period. Upon capture, all three fish were carrying the common parasitic "sea lice" (*Lepeophtheirus* sp.) suggesting recent ascent from the sea.

Behaviour at The Confluences of Tributaries

The cessation of active progression up stream, followed by stationary periods of varying duration, predominantly occurred at pools heavily frequented by anglers. The confluence of the Isla and Tay provided the most popular stopping area. The pools between the viaduct at Cargill and the head of the junction pool held a greater proportion of the tagged population at any one time than any other area within the catchment.

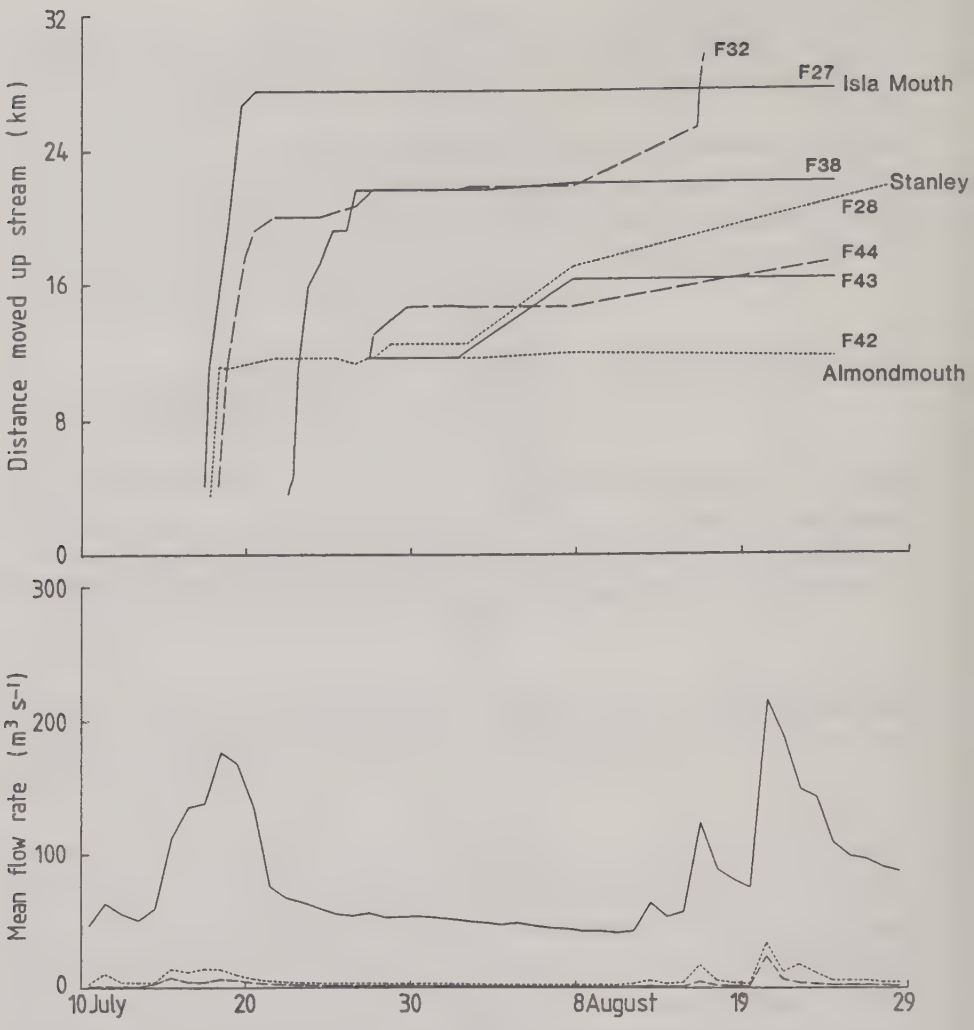


Figure 5. **The movements of F27, F28, F32, F38, F42 and F44 within the lower reaches of the main stem Tay. Mean daily flow rates recorded at Ballathie _____ , Craighall ..... and Almondbank_ _ _ _ _ on the river Almond are also shown.**

No tagged fish was recorded entering the lower reaches of the river Almond, the lowest tributary above the highest level of tidal influence.

The first tagged fish observed to enter a tributary was F5, which entered the river Isla (Table I, Fig. 1). The overall movements of F5 are shown in Figure 6. Released on 29 June, (18.50) it passed Stanley over the period 06.30–08.36 the following day (Table V), arriving at the vicinity of Isla Mouth (800 m from the confluence) at 10.02 on 1 July. It remained in this area until 4 July, whereupon it entered the lower Isla (Table IX). It was last observed in the lower reaches of the Isla in a pool 3.2 km up stream from the confluence area on the 6 July.

Six fish were recorded as entering the lower Isla on at least one occasion penetrating to a level 2 km above the confluence with the Tay (F1, F5, F13, F16, F31 and F32).

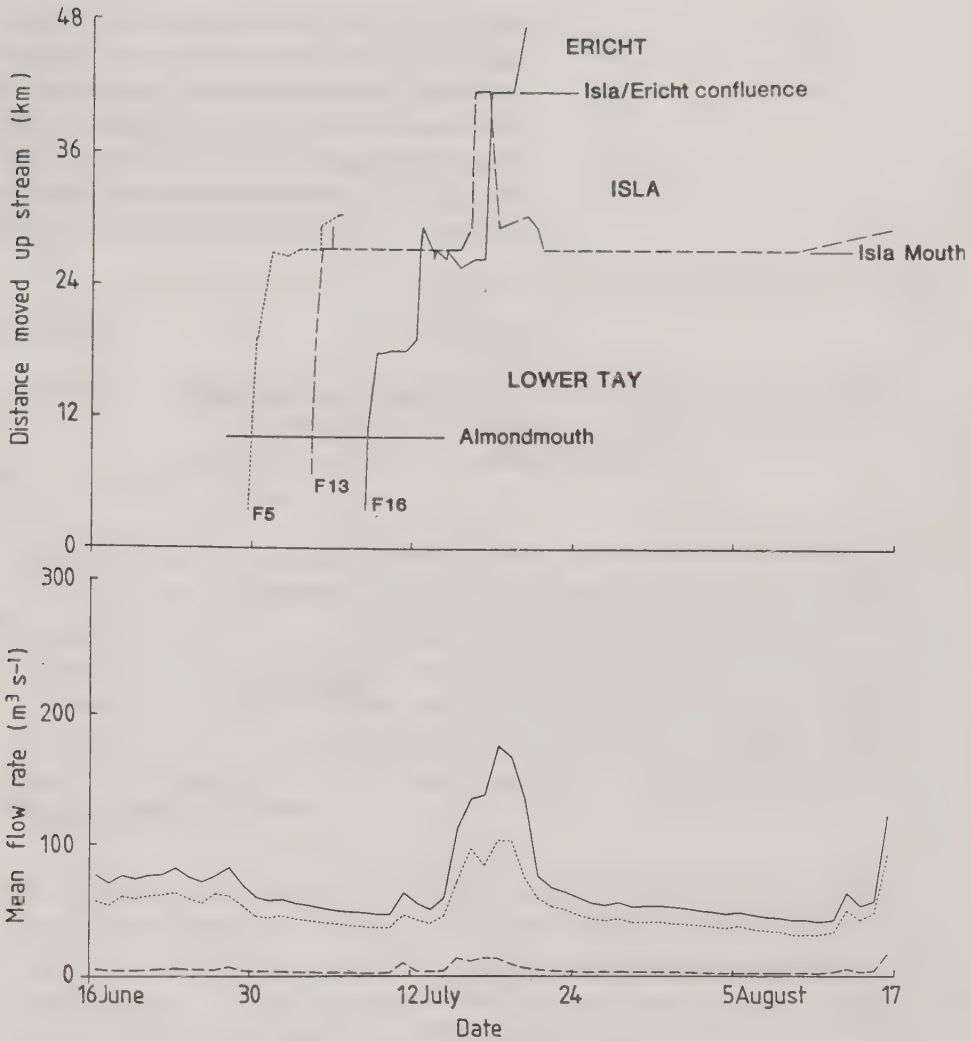


Figure 6. **The movements of F5, F13, and F16 within the main stem Tay, Isla and the lower reaches of the river Ericht. Mean daily flow rates are shown, recorded at Ballathie _____ , Caputh ..... and Craighall - - - - - - - - - - - - - - -**

Table IX shows the timing of movements of previously stationary fish into the Lower Isla (Links Farm 2.04 km), the middle reaches of the Tay (Meikleour House, 1.4 km), the area of Isla/Ericht confluence (41.82 km) and other parts of the river above Isla Mouth (including movements past ALSTNS at Dunkeld (46.97 km), at Pitlochry, and below Pitlochry dam (67.13 km). The timing of sunrise and sunset over the periods described are also shown. In the absence of increases in flows above basal levels, activity was exclusively associated with crepuscular and nocturnal periods.

Over the period 29 June to 8 July, the timing of initiation of a number of the excursions from the Tay/Isla confluence was examined by the installation of a single ALSTN in the immediate confluence area. Movements by F5, F13 and F1 were recorded. F5 (Fig. 6) left the area of the Isla/Tay confluence at 00.20 (GMT) on the morning of 4 July, passing Links farm approximately 26 minutes later (equivalent to a daily rate of progress of 113 km d^{-1}). A similar movement by F13 (Fig. 6) was recorded on 5 July, taking 49 minutes (21.11–22.00; 60 km d^{-1}), followed by an immediate return movement to the mouth of the Isla in 39 minutes (23.01–23.40).

On 7 July, F1 (Fig. 7) entered the middle reaches of the Tay, approaching the ALSTN at Meikleour House 1 hour 45 minutes later (21.55–23.40). It was located again at 00.45 on the morning of 8 July. A further movement was made at 01.15 to Meikleour but the fish later returned to the area of the mouth of the Isla. The following night, it entered the lower Isla at 22.01, and was subsequently located 2.08 km up stream at 22.35, (88 km d^{-1}) returning to the confluence area at 00.00 hrs (GMT).

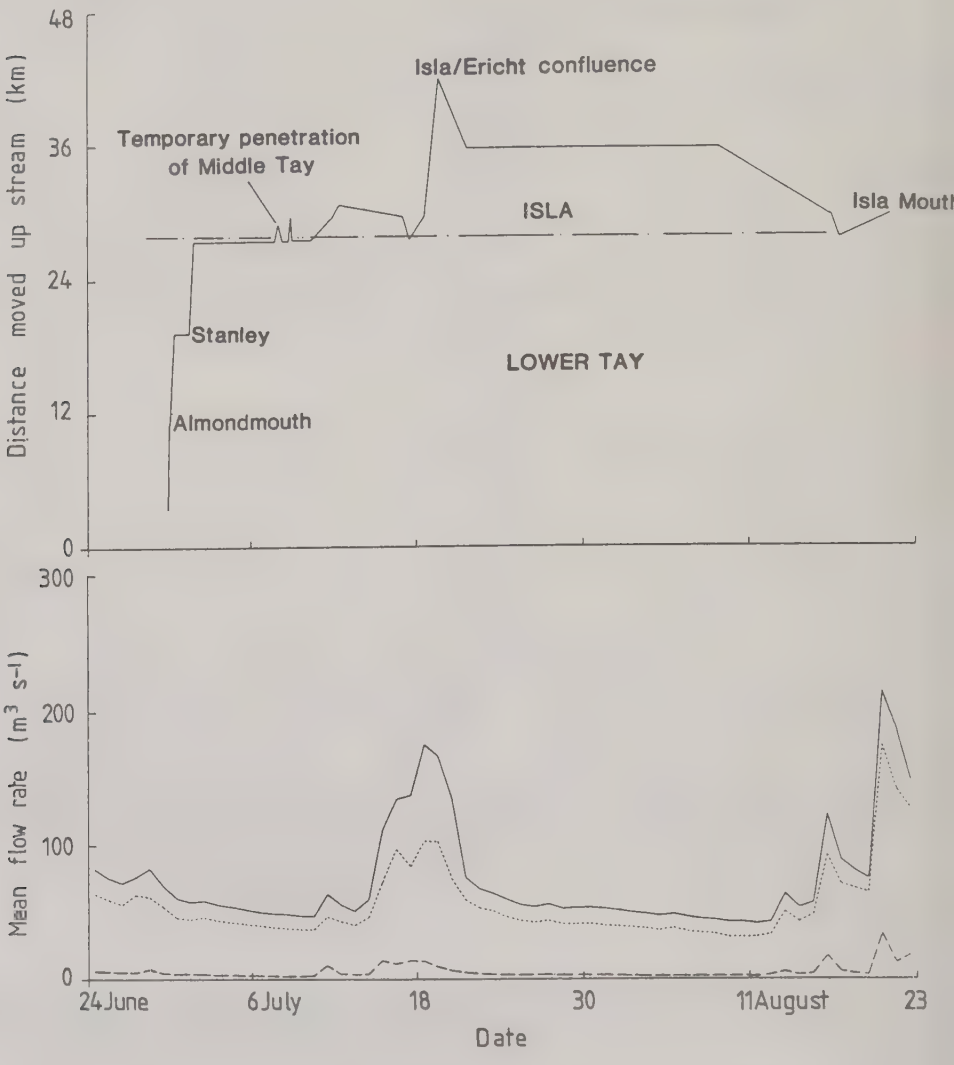


Figure 7. **The movements of F1 within the main stem Tay and the river Isla. Mean daily flow rates recorded at Ballathie _____, Caputh ....., and Craighall _ _ _ _ _ _ are also shown.**

Figures 6 and 8 shows the movements of F16. Released on 8 July (Table II), it had ascended to Stanley by 05.30 on 12 July and subsequently reached the Tay/Isla confluence 4 hours 35 minutes later (43.3 km d^{-1}). In the early afternoon it was monitored by an ALSTN in the lower Isla (Table IX), returning to the main river by the next morning and descending down stream to the area below the Viaduct at Cargill at 10.30. It returned to the Isla Mouth area at 15.06. Movement up and down this area continued up to 15 July, with the fish commonly located opposite the Ballathie Hotel (Fig. 1). On 17 July it moved up stream to Isla Mouth (06.30) and then passed the ALSTN on the lower Isla at 08.15, reaching the area of the Isla/Ericht confluence (41.82 km) at 16.25 the same day.

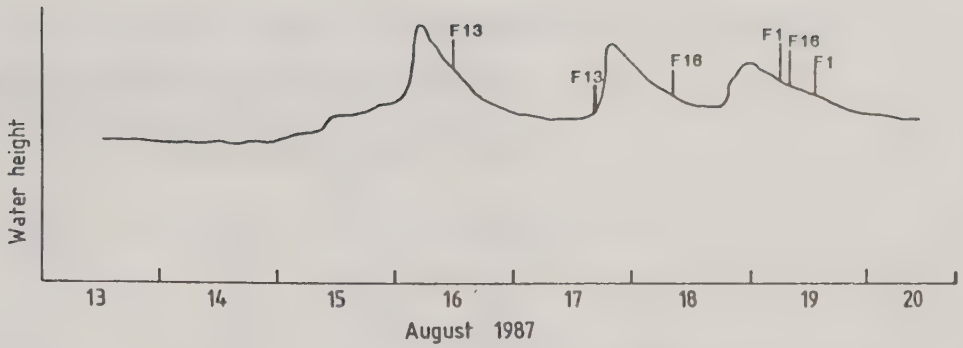


Figure 8. **The timing of recorded activity at the Isla/Ericht confluence (Fig. 1) of F1, F13 and F16 over the period 13–20 August, in relation to the simultaneous hydrograph recorded at Craighall.**

The above fish was subsequently located at the Isla/Ericht confluence by an ALSTN at 08.00 on 18 July and again at 08.00–08.05 the following day. Contact was then lost despite an extensive search of the area. It was subsequently reported to have been recaptured by an angler on the morning of 20 July below Blairgowrie in the lower reaches of the river Ericht (Fig. 1). This recapture was the only confirmed report of the ascent of a tagged fish into the lower reaches of the river Ericht over the observation period.

Two fish (F16, F1) proceeded from the Isla/Tay confluence to the area of the Isla/Ericht confluence (12.42 km up stream) within twenty four hours of their entry to the lower Isla catchment (Figs. 6, 7 and 8). As we have seen, on 17 July F16 passed the Links Farm area at 08.15 and was first recorded in the area of the Isla/Ericht confluence at 16.25 (36.5 km d^{-1}). This sustained penetration of the lower reaches of the Isla is shown in Figure 6. Similarly, F1 entered the lower Isla at approximately 22.00 on 18 July (Table IX), taking 8 hours 5 minutes to ascend to the Ericht confluence area (37 km d^{-1}). Both fish were located in the lower reaches of the Isla on previous occasions during short term excursions from the confluence area (Table IX). On both occasions, the movements were associated with significant increases in discharge above basal levels within the Isla and Ericht (Figs. 6 and 7).

Table IX

Summary of the timing of recorded movements of radio tagged salmon in the area of the Tay/Isla and Isla/Ericht confluences and main stem areas, June–September 1987

Date	Fish No.	Movement area	Time (GMT)	Sunrise	Sunset
4.7	F5	Isla	00.20	03.31	21.00
5.7	F13	Isla	21.11–22.00	03.32	21.00
7.7	F1	Tay	21.55–23.40	03.33	20.58
8.7	F1	Tay	00.45–01.15		
8.7	F1	Isla	22.01–22.35		
11.7	F1	Islat	22.25	03.34	20.51
12.7	F16	Islat	14.36–15.35*		
12.7	F19	Tayt	23.25		
13.7	F4	Pitlochry	22.35–22.45*		
16.7	F13	Islat	06.05	03.50	20.42
16.7	F16	Islat	07.55–07.56*		
			10.00–10.01*		
16.7	F1	Islat	22.05–22.06*		
			23.50–23.55*		
16.7	F13	Erichtt	12.15		
17.7	F16	Isla	08.15		
17.7	F16	Ericht	16.25–17.06*		
18.7	F13	Islat	07.30		
18.7	F16	Erichtt	08.00		
18.7	F1	Islat	13.25		
18.7	F1	Islat	22.00		
19.7	F1	Erichtt	06.05	03.54	20.43
19.7	F16	Erichtt	08.00–08.05*		
19.7	F1	Erichtt	13.45–13.55*	03.54	20.43
21.7	F13	Isla	04.10–04.11*	03.56	20.42
21.7	F24	Tay	15.34–15.56*		
24.7	F29	Tay	02.10–02.15*	04.02	20.35
16.8	F32	Islat	13.05–13.10*	04.41	19.51
16.8	F13	Islat	14.00–14.01*		
16.8	F1	Isla	17.15	04.41	19.51
	F31	Tayt	17.40–17.46*		
	F31	Tayt	19.00–19.20*		
	F1	Isla	20.40		
	F31	Isla	21.30–21.35*		
25.8	F31	Tay	11.50–11.55*	05.00	19.26
	F31	Tay	16.10–16.35*		
31.8	F29	Dunkeld	03.05–03.25*	05.11	19.14

†† reception period by ALSTNs only; GMT.

* denotes period of continuous reception by ALSTN.

** denotes timing of sunrise and sunset (GMT) for described dates for position; Latitude $56^{o}20'$N, Longitude $3^{o}20'$W.

† Movement associated with local increase in flow above basal levels.

The movements of the other fish that remained in various areas of the main Tay are shown in Figures 9 and 10.

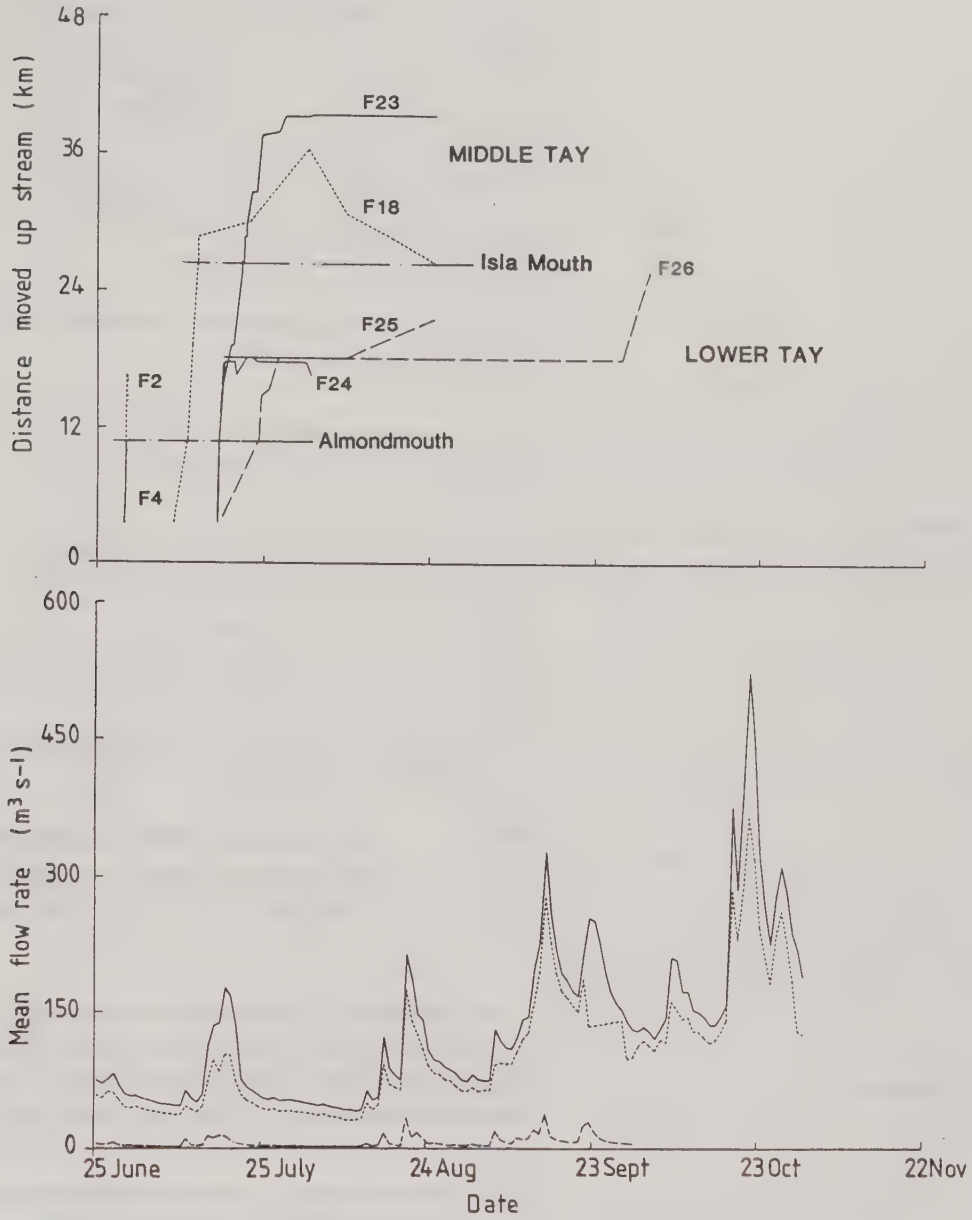


Figure 9. **The movements of F2, F4, F18, F23, F24, F25 and F26 within the lower reaches of the main stem Tay. Mean daily flow rates recorded at Ballathie _____ , Caputh ....., and Almondbank - - - - - are also shown.**

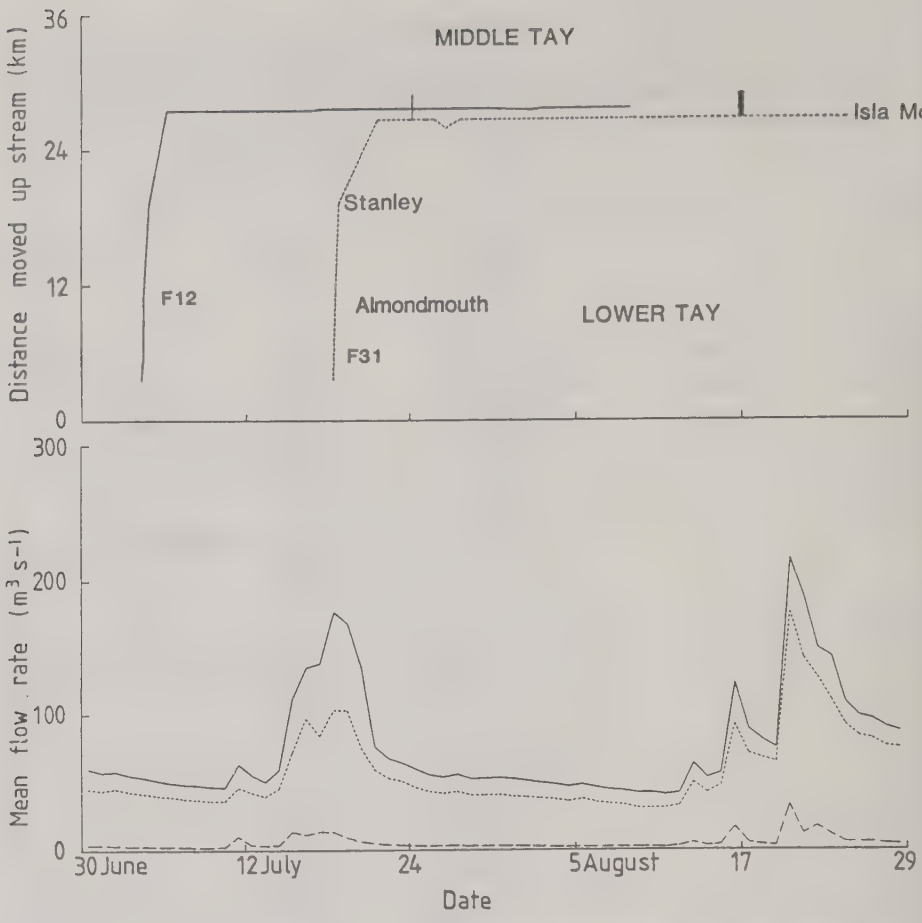
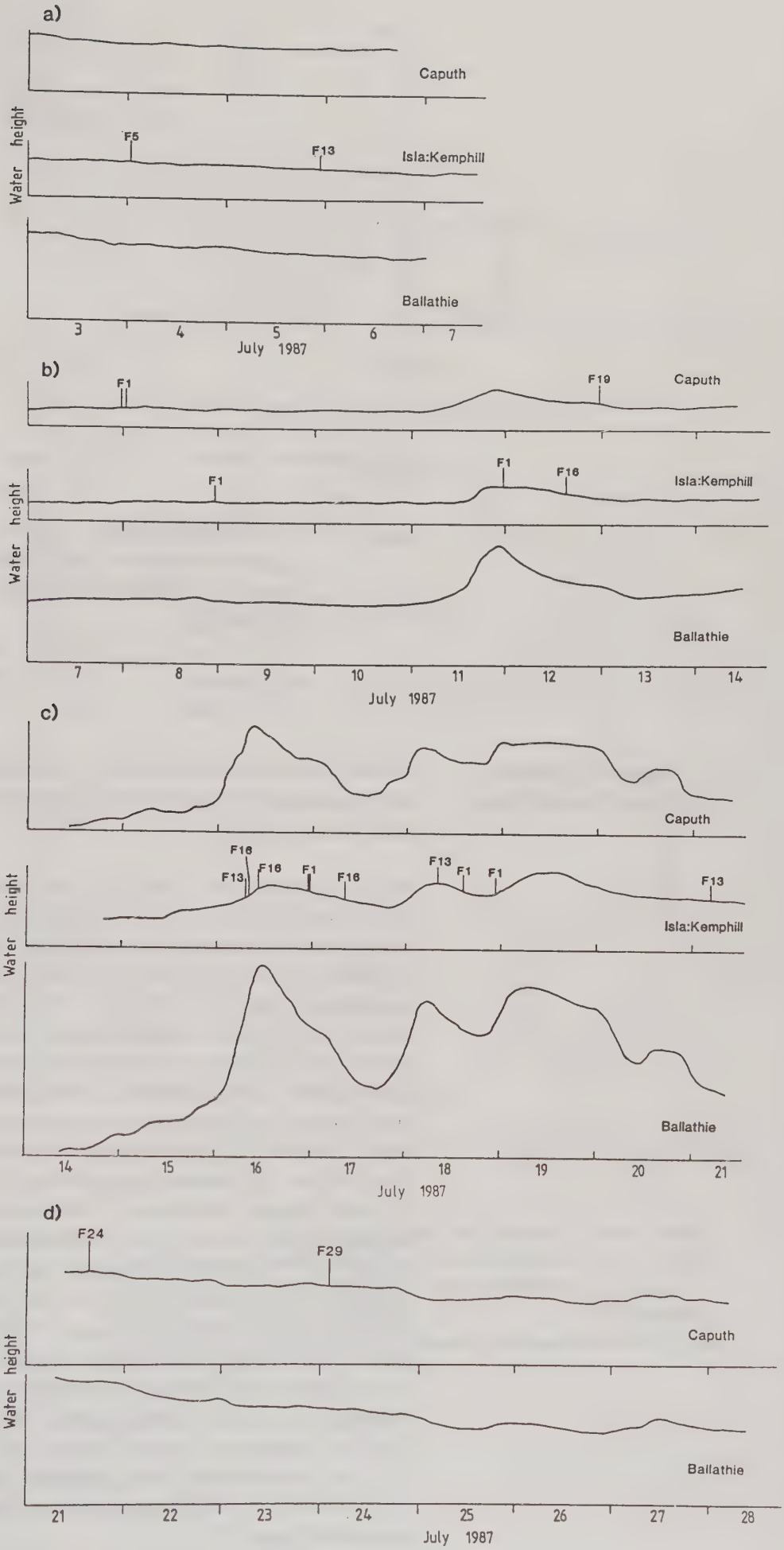


Figure 10. **The movements of F12 and F31 within the main stem Tay. Mean daily rates recorded at Ballathie _____ , Caputh ....., and at Craighall _____ on the river Ericht are also shown.**

The timing of the movements recorded in the area of the Tay/Isla confluence over the period 3 July–18 August, together with hydrographs taken from gauging stations at Ballathie, Caputh and on the lower Isla at Kemphill (Fig. 1), are shown in Figure 11.

With the exception of those movements observed on 4–10 July, movements into the lower Isla appeared to be associated with small increases in flow above basal levels in the tributary itself. Simultaneous flow records taken at the two locations on the main-stem Tay did not reveal any clear association with main-stem flow. In the absence of local elevated flows, penetration of the lower reaches of the tributary predominantly took place within the hours of darkness. A similar pattern of movement is evident within the main stem where movements outwith the initial ascent period were recorded (Table IX).



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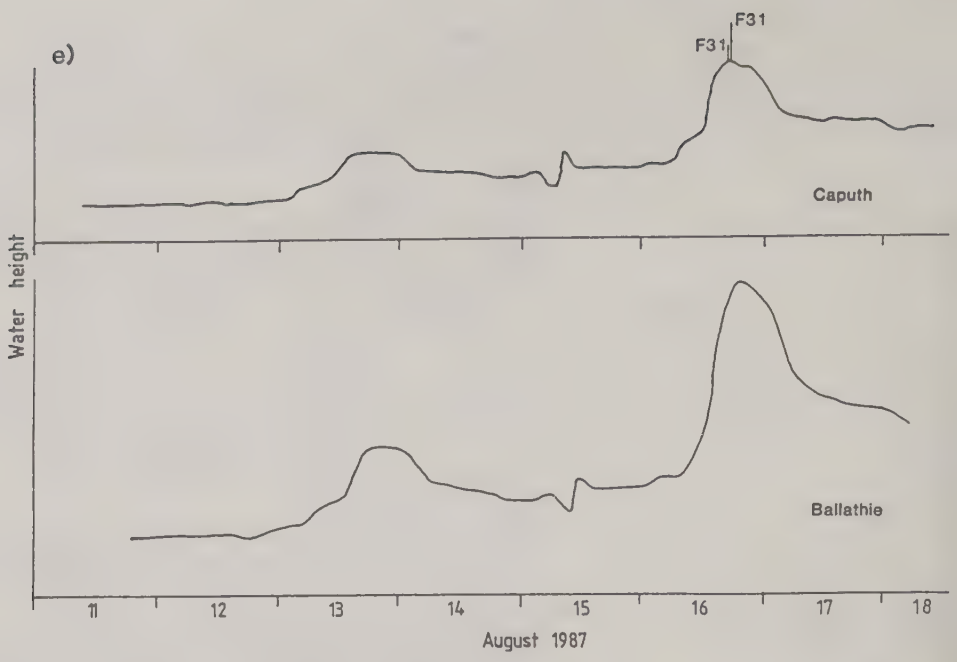

Figure 11. **The timing of movements into the middle reaches of the main stem Tay and lower Isla from the Tay/Isla confluence area (Fig. 1), in relation to simultaneous hydrographs recorded at Ballathie, Caputh and Kemphill.**

(a) 3–7 July
(b) 7–14 July
(c) 14–21 July
(d) 21–28 July
(e) 11–18 August

Movement Through a Fish Pass: Pitlochry Dam

Figure 12 shows the movements of the tagged grilse F4 and the numbers of fish per day recorded as having ascended the Pitlochry dam fish pass over the same period.

Released on 29 June (Table I), the fish moved quickly up stream to the area of the Isla/Tay confluence. It remained in this area for five days, whereupon it subsequently entered the middle reaches of the Tay and proceeded to enter the river Tummel at Ballinluig (53 km), reaching the area beneath the dam at Pitlochry (59.5 km) at 22.35–22.45 on 13 July (Table IX). The fish remained below the dam until 18 July. During this period it was located in the area of the main channel approximately 30 m down stream from the former screen positions on the eastern bank of the river. On 16 July the fish was recorded as having descended below this area by an ALSTN positioned *ca* 600 m down stream of the dam-base. The fish was last located below the dam at 09.15 on the morning of 18 July. A search of the area at 19.30 on the same day proved negative, suggesting that the fish had entered and ascended the pass within this period. Both the recorded descent from the dam base on 16 July and the entrance to and passage through the fish pass coincided with an increase in discharge at the dam over the period 15–20 July. The increase in flow was primarily due to an increase in discharge from heavy rain in the upper Garry and Tummel catchments over the previous 48 hours. No indication of the time taken to ascend the fish pass was recorded other than the intervening period between the two observations made on 18 July. The timing of these recorded movements and the hydrograph from the Port-na-Craig gauging station (below the dam; Fig. 1) are shown in Figure 13.

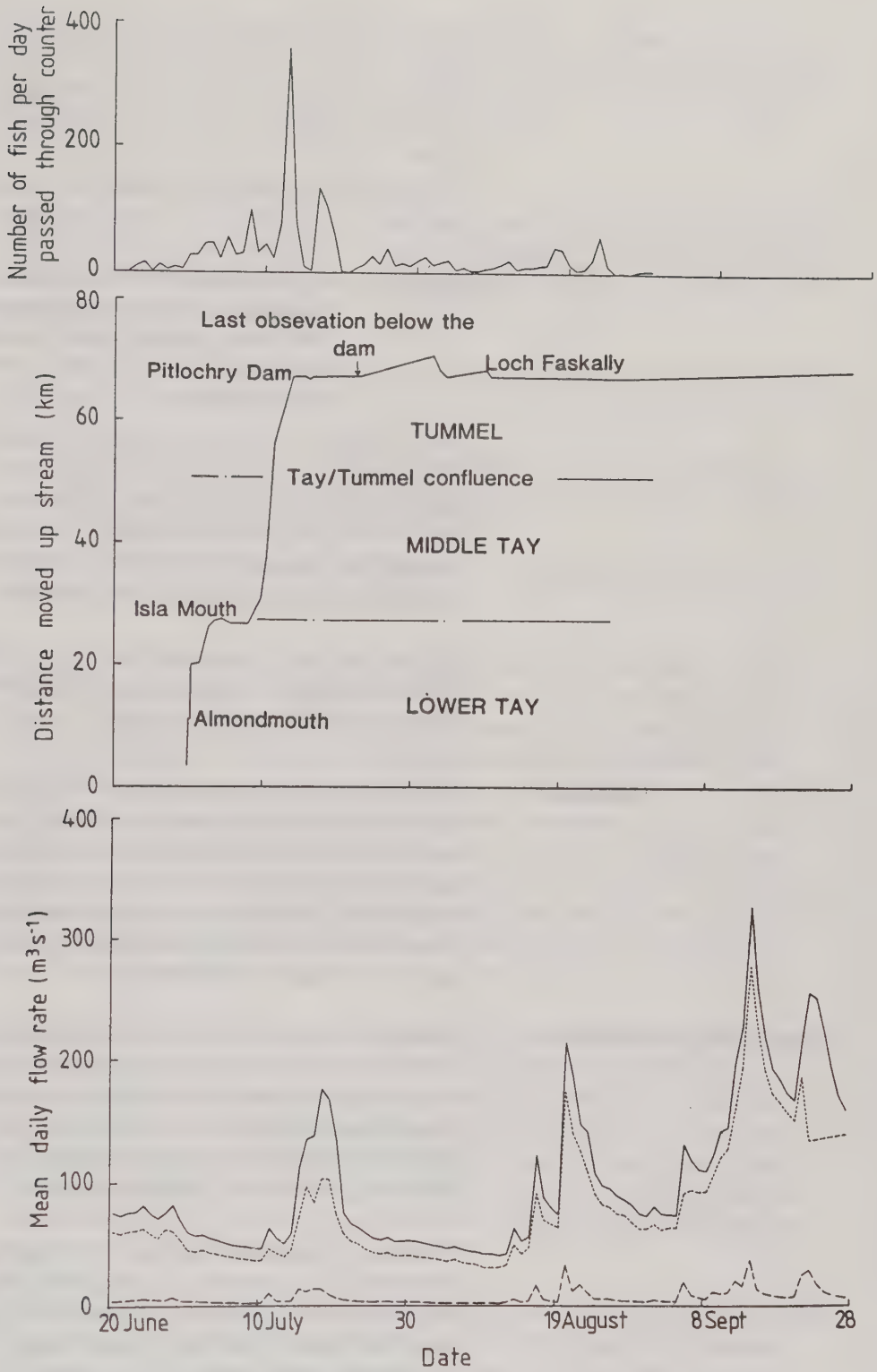

Figure 12. The movements of F4 within the main stem Tay and the river Tummel (Fig. 1). Note the period of residence below the dam at Pitlochry before ascending the fish ladder. Mean daily flows at Ballathie _____, Caputh ..... and Craighall _____ and the numbers of fish ascending the fish pass per day over the same period, are also shown.

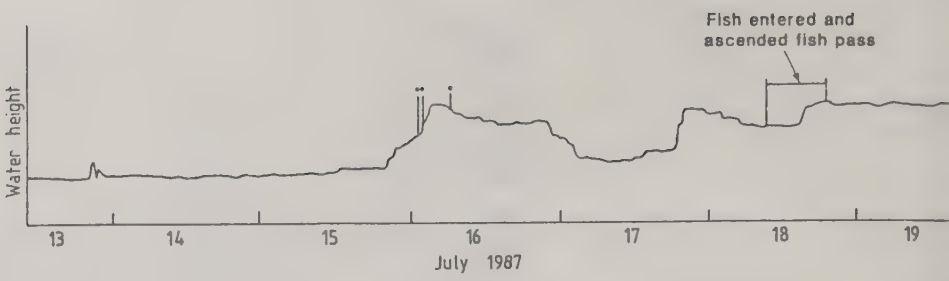

Figure 13. **The movements of F4 in the area of Pitlochry dam over the period 13–19 July in relation to the continuous hydrograph taken from the Port-na-Craig gauging station immediately below the dam (Fig. 1). The timing of temporary down-stream movements from the dam (i) are also indicated.**

On 1 August, the fish was located in Loch Faskally, where it remained up to the last observation on 27 September. During this period the fish was located in different areas of the loch on a number of occasions, both in the deep water behind the dam wall and along the eastern bank. The highest recorded penetration within the loch was in the area opposite the DAFS Freshwater Fisheries Laboratory on 1 August (16.58).

By the first week in August, owing to successive tag failure, only 18 fish were being monitored. By 27 September only five were detected during an extensive aerial survey.

Discussion

This study was conducted within a particular river system, and the fish were migrant adults entering the river over a relatively short period within a single year. It is likely that salmon enter the river Tay on every day of the year (Malloch, 1912), but this study concentrated on groups of ascending grilse (one-sea-winter fish) captured in late June and July. The movements of multi-sea-winter fish or grilse at other times of the year may prove to be different.

General Pattern of Movement

Differences were observed in the movements of grilse ascending the Tay at different times, even over the short study period. Typically, earlier migrants penetrated the catchment to a greater extent than later ones. These observations are in accord with the seasonal patterns of ascent into rivers described by others, within Scotland and elsewhere (Sedgwick, 1953; Saunders, 1967; Struthers, 1984).

In view of these observations, one might expect fish entering a single estuary to do so serially, fish travelling the greatest distance to their final spawning positions entering earliest. Accordingly, there may be an increasing likelihood of overlap in the timing of ascent through the estuary to different areas within the catchment as one considers progressively more complex river systems. At its simplest, a catchment may comprise a single main stem with tributaries which are occupied only at spawning time. At its most complex, a catchment may comprise several major drainage areas supplying major constituent streams, with holding areas occupied over the greater part of the migratory season by adult salmon. Geographically, the Tay conforms to the latter type.

Tagged fish ascended the upper part of the estuary and the lower reaches of the river over a range of river discharges. River entry was not particularly associated with the higher flows recorded. Movement through the highest tidal reaches into the lower part of the main stem was recorded during flows varying between 31% and 108% of the SMDD (seasonal mean daily discharge).

The range of flows prevailing during the movements observed in this study were broadly similar to those prevailing during fish counter studies near to the head of tide on a number of northern English rivers (see Peters *et al.*, 1973; Cragg-Hine, 1979).

Half the fish released were subsequently recaptured by the net and coble fisheries in the Tay. This level of recapture may not be typical of the Tay. The recaptured fish had only recently been tagged, and may therefore have been vulnerable to capture. Moreover fishing effort was particularly heavy at the time of tagging.

In the Tay, there are two unique factors which may potentially affect the entry of fish:

i. There is a permanent and extensive tidal fresh water area within the upper estuary, extending for *ca* 19 km from the area of Newburgh to Scone (West, 1971/2).

ii. Two productive tributaries (the rivers Almond and Isla) enter the Tay close to the head of tide.

It is commonly assumed that in an estuary fish will tend to move up stream under a particular set of flow conditions. There is, however, no reason to suppose that in the Tay, with its wide range of seasonal flows and tributaries with differing characteristics, grilse from different tributaries will necessarily ascend the estuary and river under similar conditions. Fish destined for the Almond, with its low location, its low state of flow in the summer and its late running fish (Struthers, 1984), may accumulate within the upper end of the estuary. Timing of entry from the estuary into the main river is likely to be different for different populations of fish destined for different tributaries, though at times the fish may enter the common estuary simultaneously.

vements to the Head of Tide
d within the Lower Reaches
of the Main Stem

Fish released in the upper estuary ascended quite quickly to areas above the limit of the tide at Scone. Individuals released in the early part of the tagging period generally continued moving to the area of the Tay/Isla confluence. Fish tagged later tended to curtail their initial penetration, stopping within the lower reaches of the river between Stanley and Taymount. Anglers on the Tay (basing their views on rod catches) believe that fish tend to stop below the area of the Tay/Isla confluence from the later part of July onwards.

The ground speeds recorded in this study are amongst the highest reported in the literature for Atlantic salmon within rivers. There is a marked similarity in calculated rates of ascent shown by tagged fish moving through the lower reaches of the river over the same period of time (Tables V and VIII). Hawkins and Smith (1986) described rates of ascent within the lower reaches of the river Dee (Aberdeenshire) ranging from 14.5 to 37 km d^{-1}, corresponding to 0.24–0.74 body lengths per second. Other reports using similar techniques tend to range from 4 km d^{-1} to 12 km d^{-1} (Hayes, 1953; Stasko, 1975). Since the fish are stemming the flow of the river, it is likely that the very highest rates of progress recorded within the Tay must have involved periods of burst swimming of short duration, the fish incurring an oxygen debt. Short term delays (<1 h) in ascent may represent a resting period following active exertion (Jones, 1959; Poddubnyi, 1971; and Beamish, 1978).

Whether these rates of ascent, calculated for the most part within the tidal limits of the Tay, are typical of those of fish moving into the lower part of the estuary under similar conditions of tide and main river discharge cannot be assessed. Swimming activity within estuaries may be influenced by the amplitude and stage of a particular tidal cycle (Stasko, 1975). Offshore, tidal water movements can both augment and delay the progress of fish over ground (Smith *et al.*, 1981).

Figure 3 suggests that ascent from the upper estuary into the lower reaches of the river was both rapid and sustained. In most cases, the initial movement to the position of the first provisional halt took place over a period of less than 24 hours. This activity was recorded over a wide range of river discharges and appeared to consist of a single movement initiated within the estuary and ending above the head of tide. Within the river Dee (Aberdeenshire), a similar rapid entry and ascent of the lower reaches of the river to levels *ca* 10–25 km up stream over a range of seasonal flows was observed from a number of radio-tagged spring and early summer fish in 1987 (J. Webb and A.D. Hawkins, unpublished observations).

Fish 18, F26, F28 and F29 undertook this pattern of movement into the river only after varying periods of delay within the upper estuary, suggesting that direct entry does not always occur. The rapid transit of the upper estuary observed for many fish is unlikely to be the result of handling and tagging.

Tidal influences prevail within extensive reaches within the estuaries of some larger rivers on the east coast of Scotland and particularly the river Tay (Craig, 1971/72; West, 1971/72). The rapid movements observed within the estuary of the Tay suggest that fish reduce the time they are exposed to the transitional estuarine environment.

Where delays by tagged fish have been reported within estuaries, they have tended to coincide with the lower range of seasonal flows (Menzies, 1931; Potter, 1988; Solomon and Potter, 1988). River discharge may subsequently determine the timing of entry and intensity of migratory activity in fresh water, as has been observed by means of counters and traps (Jackson and Howie, 1967; Swain and Champion, 1968; Alabaster, 1970).

In view of the range of seasonal flows during which sustained migratory activity from the estuary into the lower river has been recorded in different rivers, the influence of river discharge on fish is likely to be complex. Any stimulatory role played by water flow may determine the initiation of migration up stream from the estuary rather than necessarily modulate subsequent movements within the lower reaches of the river during the initial sustained ascent phenomenon.

Activity after the Initial Halt in the Lower River

After the first halt, subsequent movements within the river tended to be crepuscular and nocturnal. This observation conforms with reports from other workers using radiotelemetry (Hawkins and Smith, 1986), and from those monitoring fish movements by the operation of counters (Hayes, 1953; Stewart, 1973; Dunkley and Shearer 1982). Within the Dee, similar activity has been observed consistently among tagged members of a late spring population in March to May 1987 (J. Webb and A.D. Hawkins, unpublished observations) and in the autumn by members of population entering a tributary just before spawning (Webb and Hawkins, 1989).

Protracted periods of residence in particular areas of the river were recorded from all the tagged fish. Similar behaviour has been reported for fish in the Dee by Hawkins and Smith (1986). Inactivity of this kind has been observed over a wide range of local discharges and in the absence of physical barriers, with periods of residence within particular pools of up to 2–3 months being observed for some fish. Within the Aberdeenshire Dee, the final stopping positions before spawning were often at the confluences of spawning tributaries (J. Webb and A.D. Hawkins, unpublished observations). The earlier fish ascended the Dee, the longer they spent as residents of holding positions within the river.

It seems likely that those fish stopping below the Tay/Isla confluence in the latter part of the observation period were eventually destined to enter the Isla/Ericht or the middle reaches of the Tay. Whether any of the tagged fish remaining below Stanley in the latter stages of the observation period subsequently returned down stream and entered the river Almond is not known, although the observations of Struthers (1984) suggest that this may occur.

Behaviour at Confluences with Tributaries

Delays at confluences within river catchments are well documented in the angling literature (McLaren and Currie, 1972; Mills and Graesser, 1981; Ashley-Cooper, 1987), but few critical descriptions of fish behaviour in these areas exist. In particular, the effect of differential changes in discharge within the contributing catchments have not been examined and observations on the behaviour of fish in the vicinity of confluences have not been made.

Observations at the Tay/Isla confluence suggest that excursions away from the confluence in the absence of any physical barrier can be extensive and repetitive. Temporary penetration of the lower reaches of the two tributaries was common by fish from pools below the confluence. The positions held by fish at confluence areas may be determined by channel topography and pertaining hydrological conditions.

Results from several fish suggest that increases in the main stem Tay flow might not have been a prerequisite for the initiation of movement into the lower Isla before 16 July. Overall, no single discharge level was concurrent with the range of activities recorded. Sustained penetration of the tributary was generally associated with longer term increases (>12 hours) in discharge within the lower reaches of the Isla. The timing of the arrival of such increases in flows to the confluence area, in relation to the nocturnal period, might have influenced the range of activities recorded. This might be particularly so during instances of a small increase in level, not associated with a simultaneous increase in turbidity during periods associated with the lower range of summer flows. As mentioned earlier, activity was not necessarily initiated from the immediate junction area. Increases in particular tributary flows may influence the behaviour of fish some considerable distance down stream in the main stem.

A number of descents down the lower Isla from a range of penetration levels were recorded. This activity commonly coincided with declining flows and the dawn period. With the exception of F1, the cause of the apparent reluctance shown by a number of tagged fish to remain within the lower reaches of the Isla for extended periods is obscure, but may reflect the nature of this tributary during those periods of low flow. During these conditions it consisted of extensive areas of sluggish water with few defined pools, an environment with may be temporarily unsuitable for the residence of adult salmon.

The multiple entry to both the middle reaches of the Tay and the lower Isla by the same fish (F1 and F31) suggests exploratory behaviour on the part of the fish involved rather than an attempt to avoid either particular main stem or tributary flows. It has been suggested that salmon use olfactory clues to "home" to particular areas of a river catchment, down-stream movements being associated with the absence of these cues (see Hasler and Scholz, 1983). Conditions associated with elevated flows might influence the ability of some fish to distinguish different tributaries, particularly when the lower range of seasonal basal flows predominates. Return to low flow conditions from formerly elevated levels may precipitate down-stream movement.

Behaviour of Fish at Pitlochry Dam

Campbell (1987) described the extensive hydro-electric developments within the Tay catchment and considered the possible implications for salmon. Only one fish (F4) ascended the river to a point which was structurally affected by these developments. Its movements are therefore of particular interest. A period of residence shown by F4 immediately below the dam appeared to be associated with similar behaviour by a considerable number of untagged fish. Descent from the dam base coincided with an increase in flow from the dam. During large spates within the river Dee, radio-tagged fish have been observed to drop down stream from former positions (Hawkins and Smith, 1986). Some holding positions may become untenable during periods of elevated flow.

Figure 12 illustrates the association between an increase in discharge emerging from the dam and the simultaneous increase in the number of fish per day passing the fish-counter within the fish pass. The pass is of the orifice type with 34 pools, including two larger resting pools. The movements of fish through the ladder were described by Netboy (1968) Gardiner (1971) and Sturrock (1988). A detailed account of the behaviour of tagged Atlantic salmon in the vicinity of a hydro-electric dam was given by Poddubnyi (1971), although it is likely that the behaviour of fish in the area of such structures is specific to the site described.

A number of peaks in the daily ascent rate through the ladder were recorded over the period 13–21 July. Fish 4 did not ascend the fish pass on 13 July, though other fish did, suggesting that not all fish below the dam behaved the same. The role of the generating regime over this period is obscure. Despite significant fluctuations in river flows emerging from the turbines, flows through the pass structure remain constant, fish being subject to changes in discharge only before their entrance to the pass. The role of flow in stimulating the resumption of migratory activity in salmon within the river is not clear, and is likely to be complex.

Ignoring factors which set limits to migratory activity, including water temperature (Jones, 1959), there is likely to be a significant seasonal influence on migratory activity (Tinbergen, 1951; Peters *et al.*, 1973). Coincidence of movement in the main river and within tributaries with increases in local discharge has been described. In this study most of this activity was associated with movements at or near tributary confluences. However, the limited penetration of the main stem above the Isla/Tay confluence by the majority of tagged fish over the study period precluded detailed observations in the main river. Future studies within the same catchment could profitably concentrate on fish penetrating the main river.

Nevertheless, the limited observations made do suggest that migratory activity in the river Tay might be modified by the discharge regimes of both the main river and constituent tributaries. Similar observations have been made at a range of rivers by previous workers (Huntsman, 1939; Hayes, 1953; Allan, 1966; Banks, 1969; Alabaster, 1970; Webb and Hawkins, 1989). The initiation of activity in relation to the stage of the relevant hydrograph seems to vary. Banks (1969) in an early review concluded that, although the relationships between fish behaviour and physical or chemical characteristics were not yet understood, there was evidence to support the view that increased discharges were important in initiating movement. However, it has been suggested by others that changes in flow might be important only within the larger rivers in allowing the fish to ascend barriers (Hawkins and Smith, 1986; Hawkins, 1989).

To understand fully modifying effects of river flows on migratory activity, the timing of changes in local discharge levels must be considered in relation to the stage of migration reached by the fish. There will be times when fish are susceptible to increases in flow, and others when they are not. The levels of flow recorded during tracking studies should be considered in the context of seasonal trends for the particular river channel or tributary. The possibility that there are seasonal trends in the susceptibility of the fish to flow must also be considered. More critical evaluation of the flows utilised by migratory salmon must await a more detailed knowledge of seasonal changes in the behaviour of fish. Additional information is required on the initiation and movement by migrants both entering and already within a river, over a range of seasons and under different flow conditions, before those flows which are optimal for promoting the passage of fish can be defined.

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Summary

Radio tracking observations on the movements of Atlantic salmon ascending the river Tay, Perthshire, are described. The study was undertaken over the period June to October 1987. Forty two fish were captured by the net and coble fishery operating in the upper tidal reaches of the Tay estuary below Perth and then returned to the river after tagging with both conventional and radio tags.

Observations were made by a combination of active tracking along the river bank with hand-held receivers and the placement of automatic listening stations at selected bankside locations. Additional data were provided by the use of a light aircraft equipped with a radio receiver.

Most fish moved rapidly from the release areas in the upper estuary through the head of tide and into the lower river. The fish then stopped, typically 10–26 km from the release point. Movement from the estuary occurred over a range of flows, with fish released in the latter part of the tagging period curtailing their initial ascent at lower levels within the main river than earlier entrants.

The majority of tagged fish ascended to the confluence of the Tay with the Isla, and remained in this area. After the initial ascent, movements within the Tay and Tummel were associated with twilight and night only, except when there was an increase in river flow. Sustained penetration of the lower reaches of the River Isla commonly took place during spates within the Isla and Ericht. Descent observed by some fish within the Tay and Isla tended to coincide with a decline in flows from elevated levels. Individual fish penetrated both the Tay and the lower Isla from the Tay/Isla confluence.

The behaviour of a tagged fish in the area of the hydro-electric facility at Pitlochry was observed. After reaching the dam, further up-stream migration was delayed, the fish remaining in pools below the dam for *ca.* 5 days. Both short range movements down stream of the dam and the timing of subsequent movement through the fish ladder coincided with increases in water flow.

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